N93-22094

5.5 Solid Rocket Motors – Ronn L. Carpenter, Thiokol Corporation

Structural requirements, materials and, especially, processing are critical issues that will pace the introduction of new types of solid rocket motors. Designers must recognize and understand the drivers associated with each of the following considerations:

- Cost. Developers must understand the cost constraints of the users as well as the important cost drivers of solid systems and alternative technologies. The simplicity of solid rocket motors should produce significant cost savings relative to other systems, but current systems have not achieved their full potential in this area. A better understanding of solid propellants is needed to allow product improvement based less on empirical methods and more on analytical methods. Specifically, constitutive propellant theories are needed to explain how different processing techniques and high stress environments influence the properties and ultimate performance of solid rocket motors.

- Energy density. Future systems must continue to demonstrate high power output. The Space Shuttle solid rocket motors consume two million pounds of propellant in two minutes.

- Long term storage with use on demand. Although this was originally a requirement based on military uses of solid rocket motors, it is still an important consideration for civil systems which hope to demonstrate acceptable operational flexibility and cost.

- Reliability. Currently, both solid and liquid systems demonstrate reliability levels of approximately 98%. Failure mode analysis is most effective when started early in the design stage of new systems. The ability to conduct health monitoring of key design variables must be designed into new systems.

- Safety of processing and handling. To improve system safety, future propellants should be insensitive to impact and to electrostatic discharge, and they should ignite only when pressurized.

- Operability. Simplified on-site preparation of solid rocket motors will help to reduce launch delays and, as a direct result, decrease unplanned costs of space programs relying on solid rocket launch vehicles.

- Environmental acceptance. Solid propulsion systems must continue to address environmental effects of manufacturing processes, waste disposal and motor exhaust. At a minimum, the cost of toxic waste handling and disposal will continue to escalate. Ultimately, it may become necessary to evaluate the continued cost-effectiveness of current systems by carefully analyzing the expected costs, impact on performance and environmental benefits of alternatives such as solvent-free manufacturing, waste reclamation or incineration, and propellants which are chlorine- and/or metal-free.

The performance of solid rocket motors is directly related to the technology status of key system elements such as:

- Insulated Case. The case contains hot combustion gases, provides thrust takeout, and, in some cases, supports the vehicle on the pad. Cases should be lightweight, and they should also both facilitate and tolerate the shipping and handling process.

  Insulation is normally applied to the case in sheets or as a thermoplastic spray. Finding areas where the insulation has failed to adequately bond to the case is not uncommon. This implies that (1) the materials are too sensitive to the processing methods used, or (2) the effects of processing methods on bonding the insulation to the case material is not understood.

Current case manufacturing processes rely heavily on final proof tests as the primary inspection method. At this point in the manufacturing process it is often too late to easily make corrections. Improvements are needed in in-process testing to better predict and control the performance of the final product.

- Propellant. Solid rocket propellants are evaluated in terms of the system considerations described above. Mechanical strength, ease of production and nonhomogeneity reduction are also important.

- Nozzles. Nozzles typically consist of several components bonded together, and the bonded interface can cause problems. The nozzle environment is very harsh. In the entrance region, temperatures and pressures can exceed 3000° C and 700 psi, respectively.

- Chemical and Mechanical Interfaces. The most serious failures of solid rocket motors often are caused by chemical or mechnaical interface problems. This may sometimes occur because the responsibility for interfaces often resides in more than one organizational element. As a result, interface management can suffer.

Interfaces must be strong and stable over time, providing tight seals against hot, high pressure gases and corrosive chemicals. They should be easy to inspect, or they must be so robust that inspection is not necessary. Furthermore, they should be simple to process and insensitive to variations in processing procedures. This last requirement is often the most difficult to meet.

  - Chemical Interfaces. The typical solid rocket motor cross section includes the case, primer, insulation, liner, and propellant. The close contact of each of these different elements to its neighbors allows chemical constituents such as plasticizers and moisture to migrate across boundaries into adjacent materials. As a result, the key parameters of each element may change from its original, specified value. These variations must be predicted and, as much as possible, controlled to ensure that the final product will operate as intended.

  - Mechanical Interfaces. Although current designs for mechanical interfaces are strong and tight, they are also complex and involve time-consuming assembly procedures.

Solid Rocket Motors

Structural Requirements, Materials, and Processing

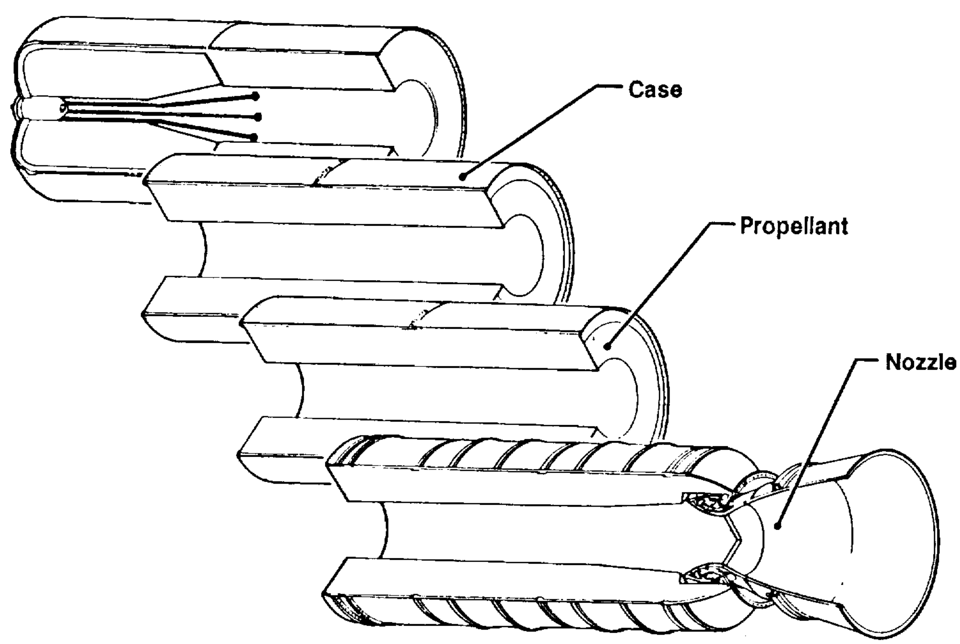
Ronn L. Carpenter

Thiokol CORPORATION
SPACE OPERATIONS

Considerations for Solid Rocket Motors

- Low cost
- High energy density
- Storable with use on demand
- Reliability
- Safe processing and handling
- Operability
- Environmental acceptability

Solid Rocket Motor Components

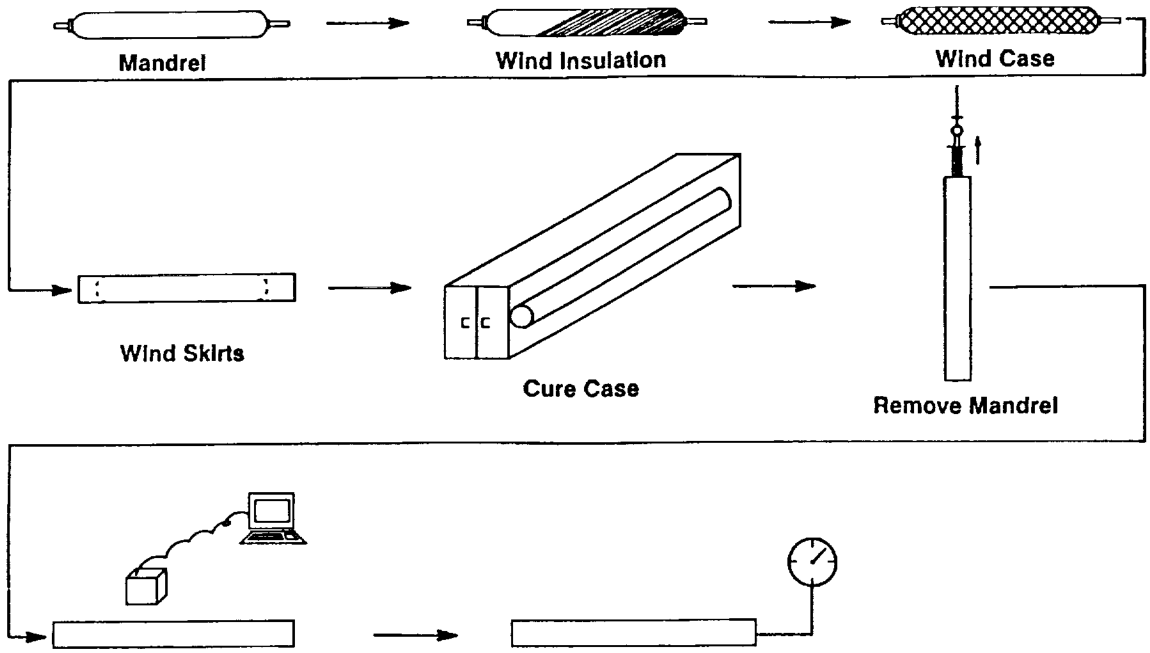


Insulated Case

Functions of Insulated Case

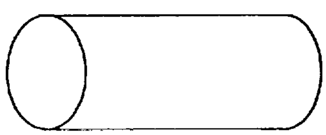
- Contains hot combustion gases
- Provides thrust takeout
- Supports vehicle on pad

Filament Wound Case Manufacturing



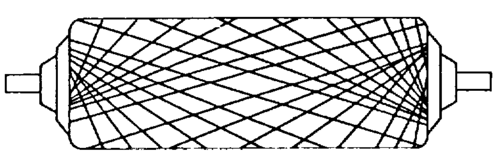
Methods for Insulating the Case

Steel Case



- Lay insulation sheets in case
- Spray thermoplastic insulation in case

Composite Case



- Either of above approaches
- Lay up insulation on mandrel
- Strip-wrap insulation on mandrel

Propellant

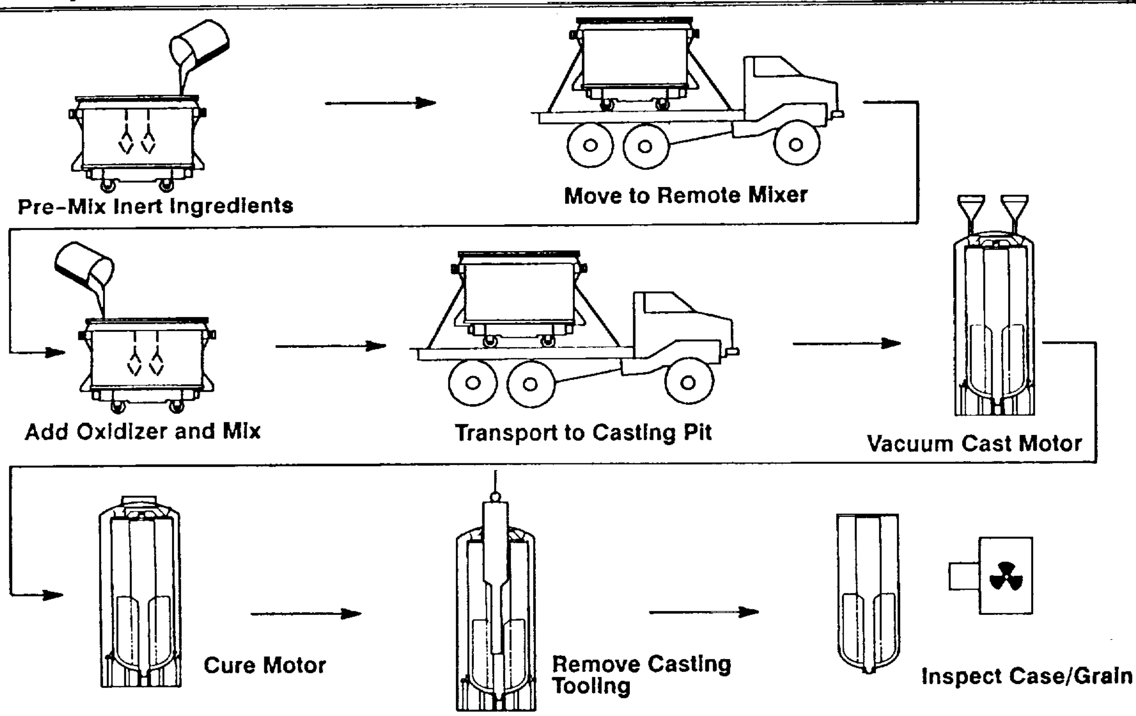
Desired Propellant Properties

- Easily produced and formed into grain configurations
- No degradation with time or exposure to ambient environment
- Safe to manufacture and handle
- Low variability
- High energy density
- Good mechanical properties
- Low-cost ingredients and production

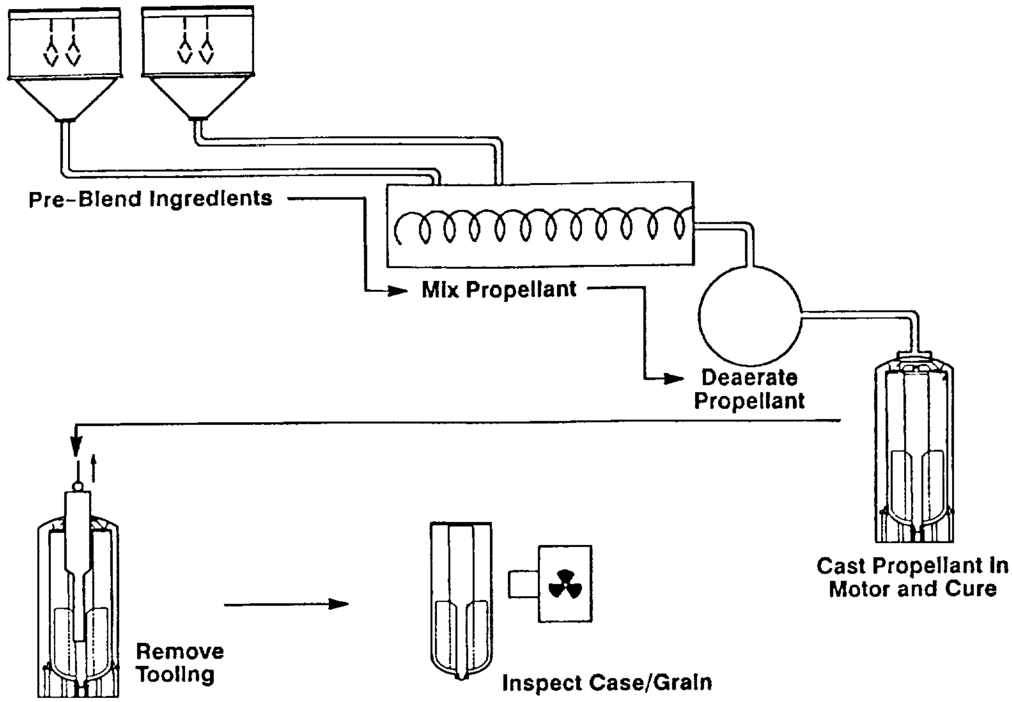
Propellant Ingredients

Ingredient	Function
AP (ammonium perchlorate)	Oxidizer
AN (ammonium nitrate)	Oxidizer
HAN (hydroxyl ammonium nitrate)	Oxidizer
$NaNO_3$ (sodium nitrate)	Oxidizer
HMX (nitramine)	Oxidizer
Al (aluminum)	Fuel
Mg (magnesium)	Fuel
HTPB (ASRM binder)	Binder
PBAN (shuttle binder)	Binder
TPE (thermoplastic elastomer)	Binder
PVA (polyvinyl alcohol)	Binder

Propellant Batch Processing

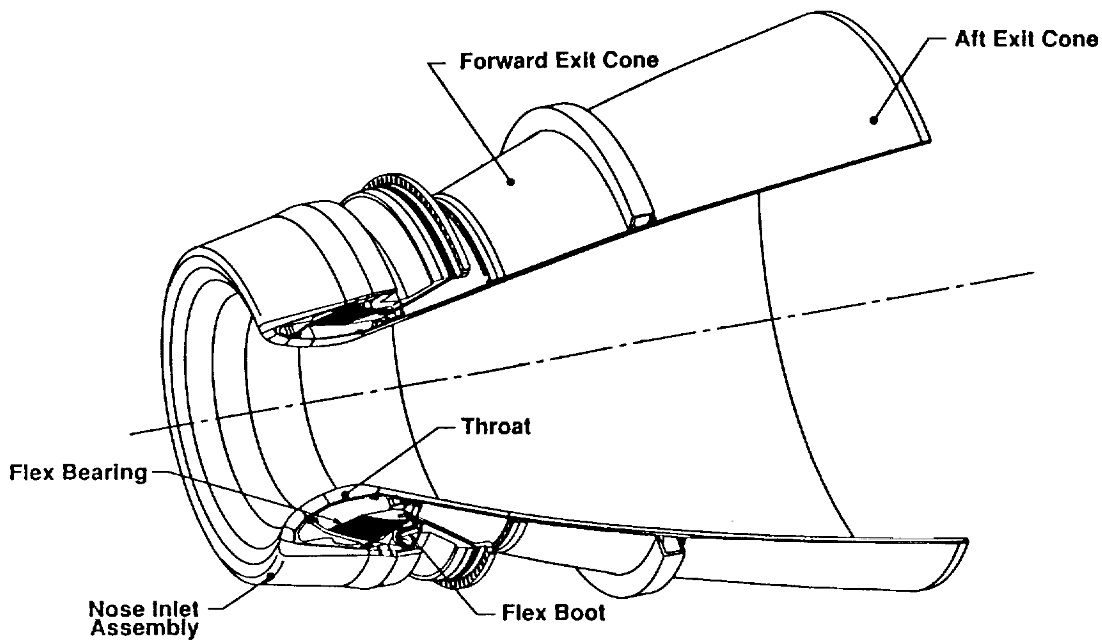


Propellant Continuous Processing

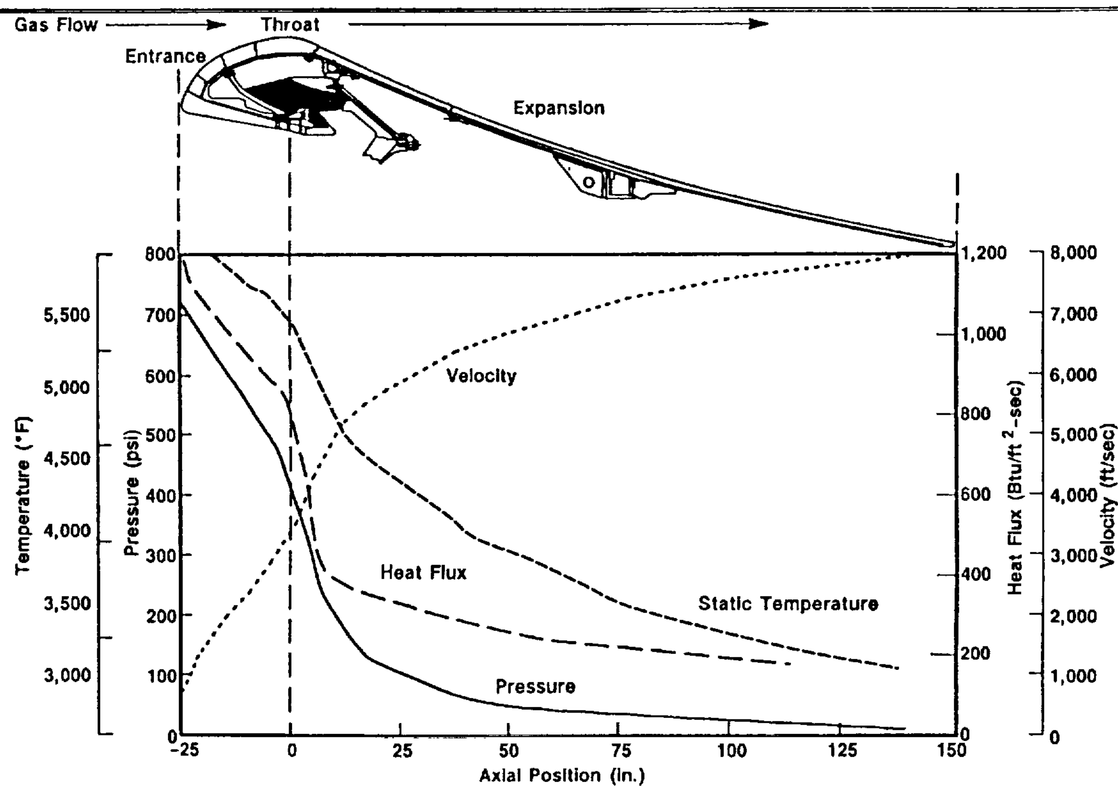


Nozzle

Solid Rocket Motor Nozzle

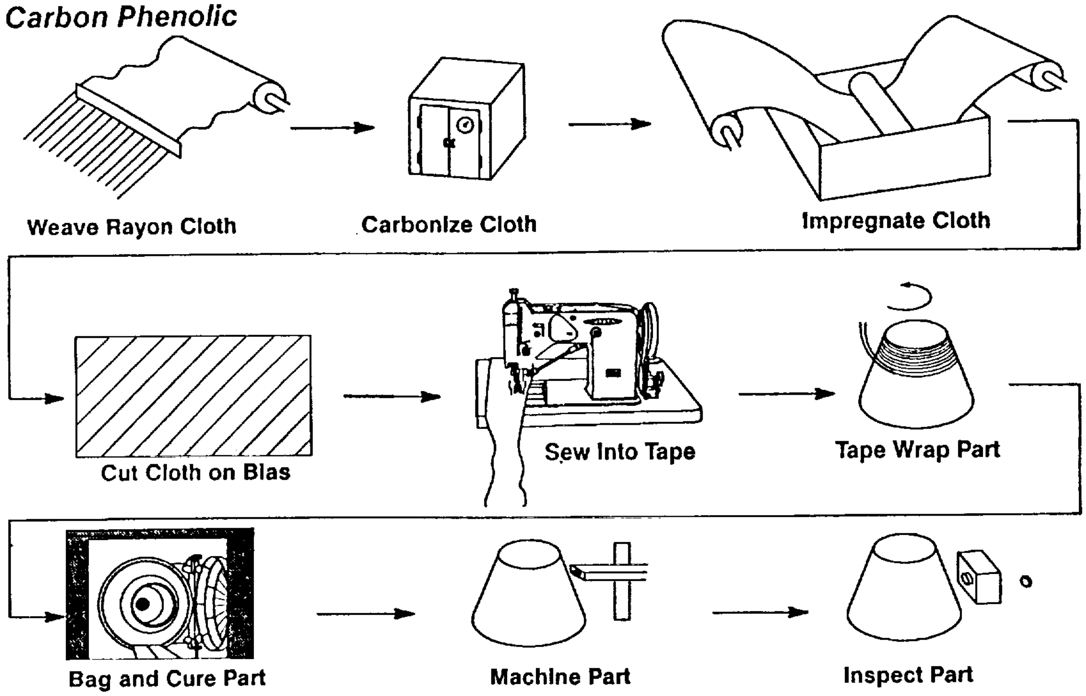


Conditions Within a Solid Rocket Motor Nozzle



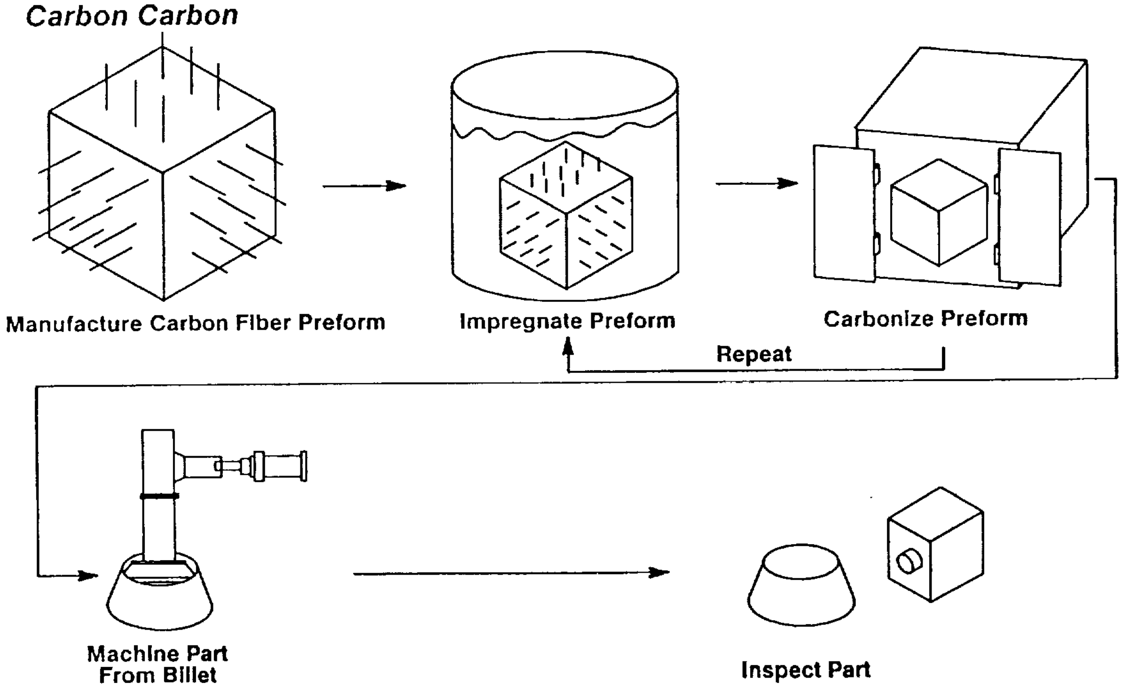
Nozzle Manufacturing

Carbon Phenolic



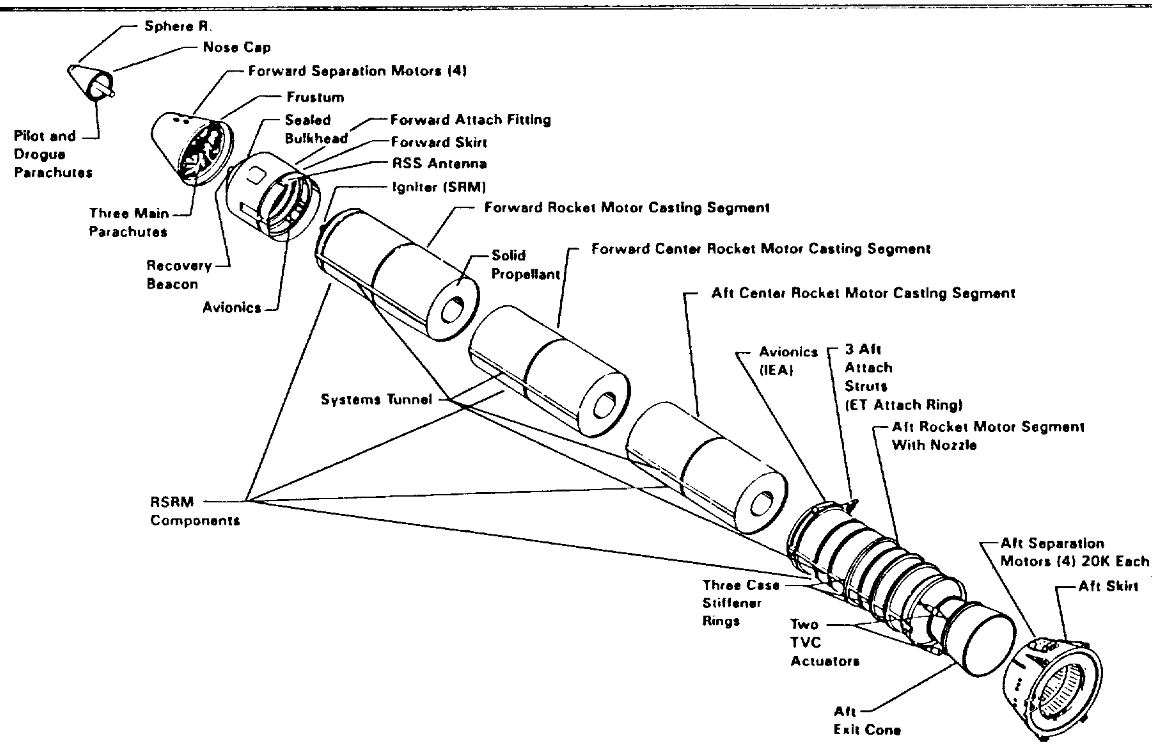
Nozzle Manufacturing

Carbon Carbon



Interfaces--Chemical, Mechanical

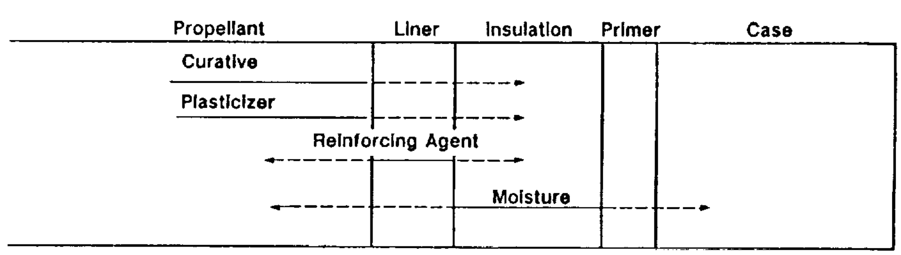
Solid Rocket Booster Components

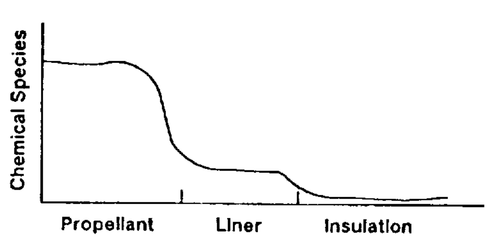


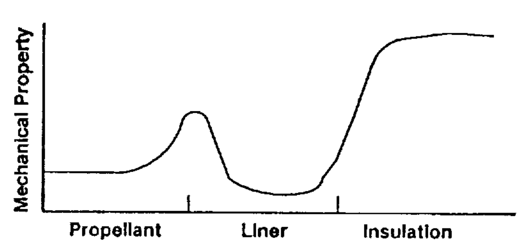
Requirements for Interfaces

- Remain stable with time
- Maintain pressure seal in hot gas (5,000°F, 1,000 psi) environment
- Provide a mechanical bond
- Act as a chemical barrier
- Be simple to process and insensitive to process variations
- Allow for inspection or be so robust as to not require inspection

Propellant/Insulation/Case Bond







Issues to Consider in Developing Solid Rocket Motor Technology

- Environment
- Reliability
- Operability
- Cost

Environmental Solid Rocket Motor Technology Needs

- Determine if there are environmental problems with current systems
  - Manufacturing processes
  - Waste disposal
  - Chemicals in motor exhaust
  - Particulates in motor exhaust
- If there are problem areas, define technology and associated cost benefits
  - Solvent-free manufacturing
  - Waste reclamation or incineration
  - Non-chlorine-containing oxidizers
  - Non-metal-containing propellants

Operability Technology Needs

- Shorten timelines associated with on-site preparation of solid rocket boosters
    - Simplify assembly and checkout processes for solid rocket boosters
    - Design attach structures and associated handling equipment that allows for rapid attachment and alignment of solid rocket boosters
- Reduce hazards associated with the handling of solid rocket boosters
    - Develop propellants that will not ignite unless pressurized
    - Develop electrostatic discharge-insensitive propellants
    - Develop impact-insensitive propellants

Reliability Technology Needs

- Improve component and system design processes
    - Understand failure modes
    - Link design variables to failure modes
    - Link process characterization and control to key design variables
    - Limit-test key design variables
    - Design in inspection and health monitoring for key design variables
- Reduce variability
    - Use reproducibility as a driver in material and process selection
    - Simplify formulations and designs
    - Identify and control critical ingredient parameters
    - Eliminate sensitive processing steps
    - Identify and control critical processing steps
    - Develop bond systems that are less sensitive to processing conditions

5.6 Combined Cycle Propulsion – Terence Ronald, NASP JPO

Terence Ronald gave a presentation on combined cycle propulsion. Due to International Traffic in Arms Regulation (ITAR) restrictions, this presentation has not been reproduced for this publication.

6.0 CHARGE TO PANELS

6.1 Samuel Venneri, Office of Aeronautics and Space Technology

Technology issues associated with materials and structures for launch systems concern metallics, composites, design concepts and, more importantly, manufacturing methods that allow cost-effective implementation of new designs by relying on new technologies. NASA conducts a great deal of research and development, but it must rely on industry to implement new technologies using new manufacturing methods.

New materials and structures technologies will help to address requirements in many application areas such as vehicle structures, cryotanks and thermal management. In addition to offering improved performance, new technologies must be affordable in terms of fabrication, sub- and full-scale testing of prototypes, and routine inspection of operational systems. The need for spacecraft to satisfy particular mission profiles introduces additional constraints on new technologies in terms of their ability to survive in a variety of space environments.

The development of new aerospace technologies now proceeds as an integrated effort in which systems developers work closely with materials and structures specialists so that performance requirements and specifications evolve along with and are tailored to the capabilities of new materials and structures. Fabrication and test of hardware are also essential elements of the development process. As a result, new systems can take full advantage of the strengths of emerging new technologies. Similarly, current space research efforts are tailoring the performance of new materials to meet the challenges of the space environment head-on.

Consider the Space Shuttle External Tank (ET), which uses aluminum (AL 2219) as the primary structural material. Current manufacturing techniques, which are based on 1970's technology, start with a block of aluminum and machine much of the raw material to produce the desired product. Changes are needed as NASA prepares to move into the 21st century. For example, as part of the USAF Advanced Launch System Program, an alternative method has been proposed which would use joining techniques such as spot welding or adhesive bonding to produce a built-up structure that makes much more efficient use of raw materials. Waste of raw materials becomes particularly important to system cost when considering a switch to high performance, high cost materials such as Al-Li.

During development and operations, some Space Shuttle main engines have encountered problems associated with blade cracking in the main turbo-pump, hydrogen embrittlement, coatings, and acoustic and thermal loading. Deterministic analysis methods used by the SSME development program did not adequately assist SSME designers in avoiding these problems because of uncertainties in the engine load spectrum and in material response properties. Instead of the standard design approaches used in the past, designers must rely on stochastic methods to accurately account for uncertainties in both (1) the exact properties of operational components (because of variability in the manufacturing process) and (2) the load placed on each individual component during each phase of its operational life. This approach requires new thinking in terms of risk analysis because it requires specification of a numerical risk of failure rather than a positive safety margin. How to select an appropriate value for the risk of failure of a given component or structure, and who should assign it, is an open question.

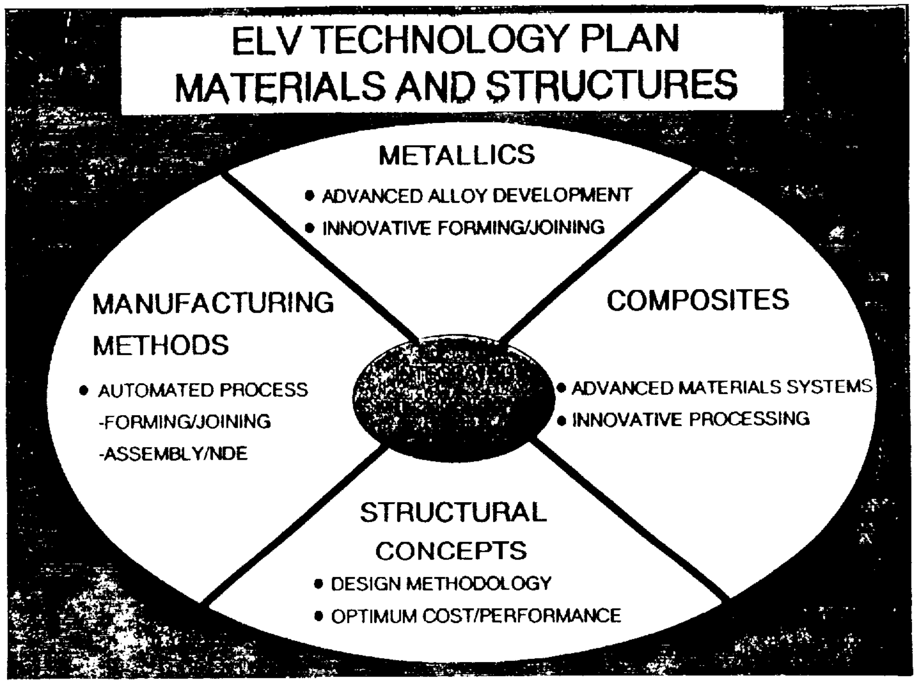
Certification of systems for flight is another key area where advanced technologies can play a role. Imbedded sensors, new methods of conducting non-destructive evaluation, and smart structures may all have important roles to play in this area.

Keeping the above points in mind, deliberations by the Workshop panels can significantly help NASA in the development of advanced technologies suitable for operational systems of the future. In particular, OAST needs to understand the interests and needs of participating organizations in terms of technology – not mission – requirements. Validation of advanced technologies and relevant manufacturing processes are particularly important. Development of point designs for large-scale missions, however, is neither practical nor cost-effective.

Another important aspect to consider is the benefit of industry-government cost-sharing, even if it is in the form of IR&D or indirect cost-sharing. How should NASA structure its efforts to work more effectively with industry? NASA and industry need to depart from business as usual.

Deliberations should consider both near-term efforts that can build on existing systems and technologies as well as longer-term efforts focused on applications such as nuclear propulsion. It may also be beneficial to investigate cost savings that may be available from the use of non-aerospace approaches to solve potential problems.

Samuel Venneri
OAST Materials and Structures Director



INDUSTRY IDENTIFIED TECHNOLOGY INTERESTS FOR EXPENDABLE LAUNCH VEHICLES

<u>MATERIALS AND STRUCTURES</u>

Advanced Al-Li Cryotanks
Isogrid Structures

Common Dome Concepts
Composite Intertank/Shroud Structues
Composite Cryotanks
LH_2 Impermeable Tank Liner

Improved Thermal Insulation
Structural Loads/Response
Tank Inspection/Testing
Test Technology

<u>MANUFACTURING</u>

Al-Li Welding
Automated Weld, Process Control, NDE

Metal Forming Methods
Advanced Composite Fabrication
Joining Technology
Automated Assembly

In Process NDE
Scale-Up/Size Limit

EARTH-TO-ORBIT TRANSPORTATION

Technology Element

Vehicle Structures and Cryotanks

Technology Sub-Elements

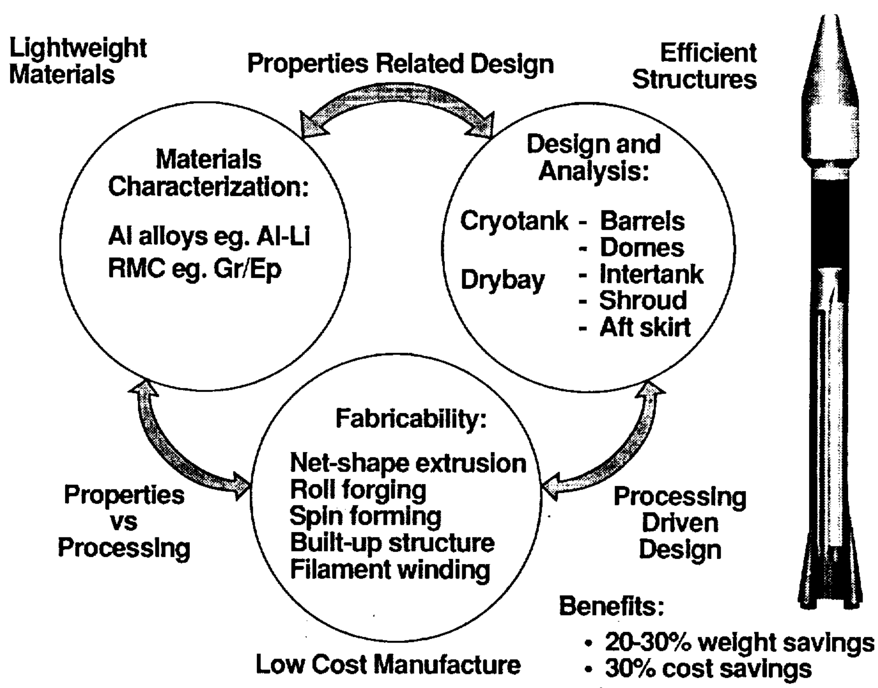
Materials Characterization

Structural Design/Analysis

Low-Cost Processing and Fabrication Development

Sub-Component Design, Fab and Test

STRUCTURES AND MATERIALS FOR LOW-COST COMMERCIAL TRANSPORTATION



SPACE TRANSPORTATION

Technology Element

Vehicle Structures and Cryotanks

Technology Sub-Elements

Materials Characterization

Materials Processing

Environmental Effects and Durability

Cryogenic Insulation/TPS

Structural Design/Analysis

Sub-Component, Design, Fabrication, and Test

ADVANCED MATERIALS, STRUCTURAL CONCEPTS, AND FABRICATION METHODS FOR VEHICLES

MATERIALS

LIGHT ALLOYS
- ALUMINUM-LITHIUM
- TITANIUM
- INTERMETALLICS

METAL MATRIX COMPOSITES

POLYMER MATRIX COMPOSITES

ADVANCED TPS
- CERAMIC MATRIX COMPOSITES
- CARBON-CARBON
- SPRAY-ON FOAM

STRUCTURAL CONCEPTS

INTEGRALLY STIFFENED SHELLS

GEODESIC SHELLS

HONEYCOMB SANDWICH

INTEGRAL STRUCTURE-CRYO TANKS

HYBRID STRUCTURE (COMPOSITES/ METAL)

FABRICATION METHODS

LIGHT ALLOYS
- SUPERPLASTIC FORMING
- DIFFUSION BONDING
- POWDER PROCESS

METAL MATRIX COMPOSITES
- HOT PRESSING
- JOINING

POLYMER COMPOSITES
- TAPE PLACEMENT
- WOVEN PLY LAY-UP
- PULTRUSION
- RESIN INJECTION
- THERMOFORMING

MATERIAL SCIENCE

POWER AND PROPULSION MATERIALS

TECHNOLOGY NEEDS

- High Temperature, Creep Resistant Materials for Nuclear Power Systems
- Very High Temperature, High Strength Materials for Nuclear Propulsion Systems
- Advanced, High Temperature Composite Systems for Nuclear Power Applications
- Low Mass, High Conductivity Materials for Thermal Management Systems

LAUNCH VEHICLE HEALTH MONITORING

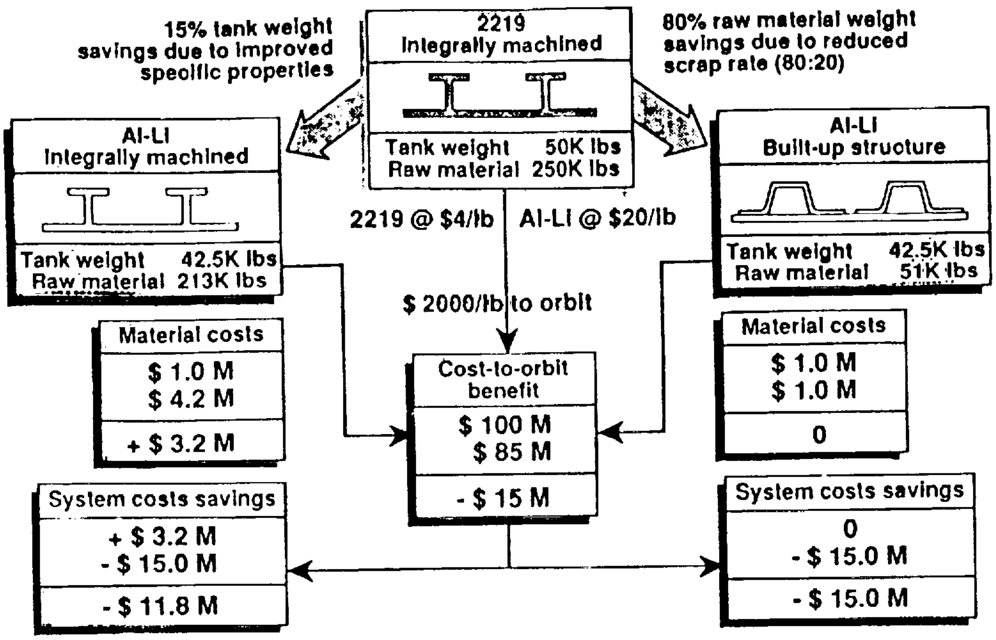
OBJECTIVE

- Develop and validate adaptive structures technology for application to health monitoring of launch vehicle structures
  - Develop/demonstrate the technology as applicable to launch vehicle structures and structural components
  - Validate technology for acceptance by launch vehicle programs

APPROACH

- Leverage extensive adaptive structures technology work performed to date for large space truss structures for use on launch vehicle structures
- Investigate cradle-to-grave structural health monitoring needs
- Coordinate development/validation effort with launch vehicle program to facilitate technology transfer to launch vehicle production
  - Perform feasibility studies based on actual requirements
  - Perform technology development for application to current and planned launch vehicles
  - Perform validation experiments required for program acceptance

BENEFITS OF USING AL-LI ALLOYS FOR CRYOGENIC TANKS



PANEL ACTIONS

- Identify and Prioritize Critical Technology Areas for Various Vehicle Classes
- Establish Potential Benefits for New Material Systems and Fabrication Methods
  - Use Current Baseline SOA as Reference
  - Provide Cost-Benefit Comparisons (X% Lighter and X% Part Count Reduction, X% Acquisition Cost Reduction)
- Explore "Nonaerospace Approach" for Structural Design
  - Higher Safety Margins and Weight for Lower Vehicle Cost
- New Material Concepts for Engine Designs
  - Ceramic and Carbon-Carbon Nozzles, Turbines, etc.
  - High Temperature Composites
- Proposed NASA/Industry Teaming Approaches
  - Specific Technology Development Activities
  - Potential for Cost Sharing

MATERIALS AND STRUCTURES TECHNOLOGY PROGRAM FOR SPACE TRANSPORTATION (continued)

- Combined NASA Funding and Industry Cost-Sharing (IR&D)
- Comprehensive Technology Program Plan
  - Near-Term Requirements
  - Far-Term R&D

MATERIALS AND STRUCTURES TECHNOLOGY PROGRAM FOR SPACE TRANSPORTATION

- Identify Industry Interest and Needs
- Establish Industry/NASA Team Concept
  - Jointly Planned Programs
  - Use NASA NRA to Solicit Competitive Approaches
- Technology Development and Validation
  - Evaluate Cost-Effective Manufacturing Concepts
  - Establish Materials Screening and Testing Activity
  - Develop Fabrication Methods
  - Establish Structural Demonstration Program
    - * Subcomponent Level
    - * Full-Size Test Articles
    - * Validated Design Concepts

NASA AERONAUTICS STRATEGY FOR TECHNOLOGY DEVELOPMENT

- Focus on Industry Requirements and Needs
  - Integrate NASA/Industry Teams: Aerospace Primes; Material Suppliers; Fabrication Companies; NASA
  - Establish Critical Technology Objectives and Goals
- Establish New Approaches for Program Implementation
  - Requires Material Suppliers Working with Prime Contractors
  - Compete for Best Ideas Using NRA
- Use Workshops, Conferences as Mechanisms to Disseminate Technical Data and Accomplishments

NASA AERONAUTICS STRATEGY FOR TECHNOLOGY DEVELOPMENT (continued)

- Technology Hardware Demonstration Programs Final Product
- Requires "Technology" Project Office Activity at NASA
  - In-House Programs Included in Critical Path
  - Industry Teams Compete Ideas
  - Technology Transfer of R&D into Product

6.2 Chester Vaughan, Office of Space Flight

The Space Shuttle will remain in use through the 2015-2020 time frame. That is a long time to use technology that dates back to the 1970's, although there will be opportunities to initiate block changes to upgrade the Shuttle fleet. The Assured Shuttle Availability program will prevent problems associated with the obsolescence of parts based on 30-year-old designs as well as improve Shuttle performance. The elusive Space Shuttle hydrogen leaks during the summer of 1990, which were caused by a total of four seals which had undergone ineffective acceptance testing or improper installation, demonstrated that small problems in critical areas can cause major impacts on operational programs.

NASA is preparing to embark on the deployment of Space Station *Freedom* which will remain operational for 30 years. Other major initiatives include the NLS program. Introducing new technology into these and other programs will be a great challenge because of both the cost and risk associated with transferring new technologies to operational space systems.

During the conception of the Space Shuttle, the goal was to develop a fully reusable, two-stage launch system capable of 65 launches per year for about $300 per pound of payload delivered to LEO. Although the Space Shuttle clearly provides unprecedented and still unique capabilities, it is also true that budget and technical realities have prevented NASA from accomplishing its early goals in terms of affordability and operability.

From a technology point of view, there is an opportunity to examine only a limited number of new concepts and vehicles. Therefore, NASA must carefully invest its resources to maximize their payoff. Limiting the number of initiatives will ensure that individual efforts have enough resources to make a real difference in NASA's future.

Nonetheless, a broad technology base is essential to maintain U.S. leadership in space. With respect to materials and structures, the emphasis should be on:

- Materials and processes for selected applications

- Design and construction methods for space-based systems

- Use of space as an R&D facility, as NASA demonstrated with the Long Duration Exposure Facility

The deliberations of the Workshop Panels should attempt to answer several key questions:

- What needs to be done to make new capabilities technically viable?

- Can improved materials technologies alone provide the desired capability?

- What relative priority should NASA assign to the recommended efforts?

- What are the expected benefits to the NASA user?

- Is the development and operation of the proposed new technology likely to be affordable?

- Are there other potential sponsors or users besides NASA?

If NASA looks at things a little differently, it may be able to use existing and future assets to develop new concepts with greater effectiveness. It is also important to consider factors such as the cost impact of using materials which have limited or no use outside NASA and which are available from only one or two vendors.

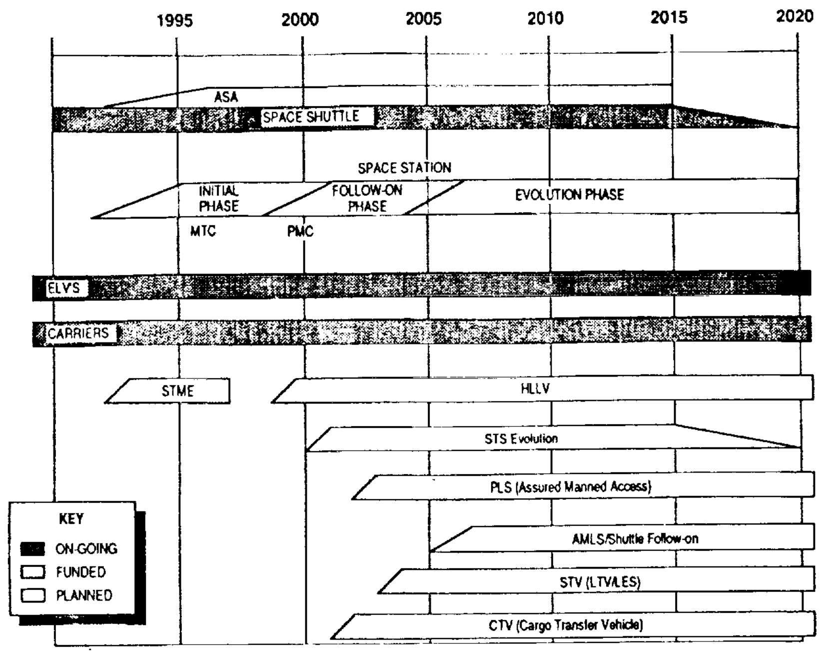
OSF - USER NEEDS

AN INTRODUCTION
TO THE
MATERIALS AND STRUCTURES WORKSHOP PANELS

CHESTER A. VAUGHAN
Chief Engineer and Director,
Technical Integration & Analysis Div.
Office of Space Flight,
NASA Headquarters

Office Of Space Flight

REFERENCE SCHEDULE FOR TECHNOLOGY IDENTIFICATION



OSF - STRATEGIC PLAN

- UTILIZE SHUTTLE FOR MANNED MISSIONS THROUGH 2015-2020

- DEVELOP AND OPERATE SPACE STATION FREEDOM FOR 30 YEARS
  - FIRST ELEMENT LAUNCH (FEL) IN 1996

- DEVELOP NLS AND CTV AS A COMPLEMENT TO SHUTTLE FOR CARGO

- DEVELOP ALTERNATIVE TO SHUTTLE FOR MANNED MISSIONS
  - START IN 2005-2010 TIME FRAME

- IMPLICATIONS OF THE OSF STRATEGIC PLAN -
  "REALITY OF NEW PROGRAM OPPORTUNITIES FOR IMPLEMENTING NEW TECHNOLOGIES IS LIMITED"

- CHALLENGE FOR EXISTING AND NEAR TERM PROGRAMS
  - LOOK FOR OPPORTUNITIES TO UPGRADE THROUGH BLOCK CHANGES

KEY ISSUES FOR THE PANELS TO ADDRESS

- NASA STRATEGIC PLANNING SUGGESTS SEVERAL NEW MAJOR PROGRAM ACTIVITIES
  - NLS
  - CTV
  - SEI

- ONLY A LIMITED NUMBER OF PLANNING OPTIONS AVAILABLE

- NEED IS TO IDENTIFY AND PRIORITIZE THOSE ACTIVITIES THAT NASA CAN / SHOULD PURSUE

- THREE AREAS FOR CONSIDERATION ARE APPARENT:
  - MATERIALS AND PROCESSES ISSUES FOR SELECTED APPLICATIONS
  - DESIGN AND CONSTRUCTION METHODS FOR SPACE BASED SYSTEMS
  - UTILIZATION OF THE SPACE R & D FACILITY FOR CHARACTERIZATION

HOW CAN / WILL THE USER COMMUNITY UTILIZE MATERIALS AND STRUCTURES TECHNOLOGIES?

CHARGE TO THE PANELS

- OSF HAS PROVIDED TECHNOLOGY REQUIREMENTS TO OAET (Apr. 1991) M AJOR AREAS OF INTEREST IN M & S:
  - Advanced Heat Rejection Devices
  - Aluminum-Lithium Characterization
  - Thermal Protection Systems For High Temperature Applications
  - Orbital Debris Protection
  - Environmentally Safe Cleaning Solvents, Refrigerants, & Foams

- THREE PANELS WERE FORMED TO ASSESS THE M & S TECHNOLOGY BASE
  - Propulsion Systems (Incl. Advanced Nuclear)
  - Vehicle Systems
  - Entry Systems

- OSF HAS INITIATED BRIDGING PROGRAMS AS A RESULT OF TWO PREVIOUS REVIEWS (Avionics & Propulsion)
  - Aluminum - Lithium Characterization
  - AGN&C
  - Electro-mechanical Actuators
  - Vehicle Health Monitoring (New Start, FY92)

- PANEL DELIBERATIONS ARE CRITICAL TO THE IDENTIFICATION AND PRIORITIZATION OF OSF ADVOCATED TECHNOLOGIES
  - Define Specifically What Needs To Be Done To Make The Capability Technically Viable
  - Does Improved Materials Technologies Alone Provide This Capability
  - Provide Some Perception Of The Relative Priority; What Is The Benefit To The NASA User!
  - Can We Afford To Fully Mature It; ---and Then Use It
  - Are There Other Apparent Requirements / Sponsors ?

OSF Technology Requirements Evaluation

NASA Program Unique Technologies

1 Vehicle Health Management
2 Advanced Turbomachinery Components & Models
3 Combustion Devices
* 4 Advanced Heat Rejection Devices
5 Water Recovery & Management
6 High Efficiency Space Power Systems
7 Advanced Extravehicular Mobility Unit Technologies
8 Electromechanical Control Systems/Electrical Actuation
9 Crew Training Systems
* 10 Characterization of Al-Li Alloys
11 Cryogenic Supply, Storage & Handling
* 12 Thermal Protection Systems for High Temperature Applications
13 Robotic Technologies
* 14 Orbital Debris Protection
15 Guidance, Navigation & Control
16 Advanced Avionics Architectures

Industry Driven Technologies

Signal Transmission & Reception
Advanced Avionics Software
Video Technologies
* Environmentally Safe Cleaning Solvents, Refrigerants & Foams
Non-Destructive Evaluation

(*) OSF Materials Technology Requirements

SPACE R&D FACILITIES

- **USE SPACE ENVIRONMENT TO CHARACTERIZE ADVANCED MATERIALS**
  - Atomic Oxygen
  - Radiation Exposure
  - Cycles At Environmental Conditions
  - Orbital Debris, Etc. (Physical Impacts)
  - In-Space Fabrication
- **CONSIDER "LDEF" TYPE PROGRAMS TO GAIN ESSENTIAL CONFIDENCE IN CURRENT AND NEW MATERIALS, MATERIAL PROCESSES & FUNCTIONS**
  - Establish Partnership Between Code R & Code M
  - What Can /Should Be Implemented On SSF To Achieve Long-Term Objectives

DESIGN / CONSTRUCTION TECHNIQUES

- **IDENTIFICATION & DEVELOPMENT OF INNOVATIVE STRUCTURAL DESIGN CONCEPTS**
  - MECHANISMS FOR DEPLOYMENT OF LARGE SPACE STRUCTURES
    - Antennas
    - Solar Collectors
    - Large Truss
    - Aerobrakes
    - Etc.
  - INNOVATIVE DESIGNS FOR ENVIRONMENTAL SHIELDS
    - Micrometeorite
    - Radiation (Natural and Nuclear Propulsion and Power Systems
  - INNOVATIVE DESIGN CONCEPTS FOR IN-SPACE ASSEMBLY
  - TECHNIQUES FOR VERIFICATION
- **POTENTIAL / CANDIDATE MATERIALS AND PROCESSES**
    - Aluminum - Lithium
    - Metallic - Composites
    - In-Space Material Processing/Fabrication/Assembly

MAJOR MATERIALS AND PROCESSES ISSUES

- **PROGRAM MANAGERS ARE RELUCTANT TO CHANGE METHODS DUE TO TECHNICAL AND COST UNCERTAINTIES**
- **LIFE AND CYCLIC LIFE (OPERABILITY) ISSUES MUST BE ADDRESSED AND DEFINED UPFRONT**
  - MINIMUM GAGE CRYO TANKAGE
  - MLI
  - NUCLEAR POWER RADIATION EFFECTS
- **MATERIALS SELECTION / MATURATION / CHARACTERIZATION MUST ACCOMMODATE MORE THAN ONE APPLICATION**
  - A SINGLE PROGRAM CANNOT BE THE SOLE SUPPORT OF MATERIALS DEFINITION, CHARACTERIZATION, MANUFACTURE AND TESTING
- **EASE OF PRODUCTION AND REPRODUCIBILITY OF PROPERTIES**
  - TECHNIQUES MUST BE MODERNIZED/ IMPROVED
  - INDEPENDENT MANUFACTURING PROCESSES WITH PROCESS CONTROL
- **SELECTED MATERIALS MUST BE AMENABLE TO NON-DESTRUCTIVE EVALUATION (NDE) TECHNIQUES**
  - WHEN NEW
  - AS A FUNCTION OF AGE, CYCLES, EXPOSURE
  - REWORK: TO MINIMIZE AND/OR DETERMINE WHEN

LONG DURATION AND / OR SPACE BASED, MULTI-MISSIONS REQUIRE NEW METHODS / NEW WAYS OF DOING BUSINESS

MATERIALS DEVELOPMENT WITH SHORT TERM TERRESTRIAL OR IN-SPACE CHARACTERIZATION OF PROPERTIES IS INADEQUATE AND INSUFFICIENT FOR LONG TERM APPLICATIONS

CLOSING COMMENTS

- **RIGHT PEOPLE COMMUNICATING WITH ONE ANOTHER TO DO THE JOB**
  - Code MD Hqs. Program Office Representatives
  - Code RM Hqs. Program Office Representatives
  - Field Center Personnel
  - Key Industry Technologists Participating

- **AVIONICS & PROPULSION SYMPOSIUMS HAVE BEEN HIGHLY SUCCESSFUL AND PRODUCTIVE TO THOSE PARTICIPATING:**
  - Follow-On Activities Are The Result

- **VERY IMPORTANT ACTIVITY TO NASA FOR FUTURE PROGRAMS**
  - Provide Good Technology Foundation

7.0 PANEL SUMMMARY REPORTS

The final paper presentations were made on the final day of the workshop. This section includes the final presentations by the Vehicle Systems Panel, the Propulsion Systems Panel, and the Entry Systems Panel. Papers presented during the individual panel deliberations are included in Sections 8.0, 9.0, and 10.0.

7.1 VEHICLE SYSTEMS PANEL

7.1.1 Final Presentation